Viscosity of molten Fe-Ni binary alloy

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ABSTRACT

Although the iron group elements are very important materials industrially, large discrepancies are frequently found in their thermophysical properties in the molten state such as viscosity. Therefore, the viscosity of Fe-Ni binary melt was investigated by using an oscillating viscometer which was improved to obtain highly reliable viscosity. The viscosities obtained for several compositions showed very good Arrhenian behavior in entire temperature ranges. The scatter of the data for individual composition was only 0.2-0.4% and the maximum uncertainty accompanied by the measurement was estimated within about 3%. The isothermal viscosity decreased monotonously with an increase of the nickel content. The activation energy of the viscous flow also decreased with an increase of the nickel content. These results suggest that the Fe-Ni alloy is a simple liquid and is almost no specific interaction between the components.

1. INTRODUCTION

The iron, nickel and their alloys are very important industrially, and Fe-Ni alloy is an essential system of many highly valuable alloys such as the super alloys and the stainless steel, etc. However, their thermophysical properties in molten sate such as the viscosity are not well known, indeed big discrepancy in the viscosity and also the different composition dependence are found in the literature values like to other alloy systems at higher temperatures. On the other hand, the authors have investigated the viscosity of molten metals and alloys at higher temperatures to clear the viscosity behavior through the development and improvement of high precision oscillating viscometer for the high temperatures. In this study, the viscosity of molten Fe-Ni alloys have been measured in whole composition range and up to 1880K, and have obtained the reliable absolute viscosity, the composition dependence and the activation energy for viscous flow.

2. EXPERIMENTAL

As the most molten metals have low viscosity and the molten iron alloys are at very high temperature, the method available for measuring viscosity is actually limited to be only an oscillating method. The authors have developed and improved the viscometer, and have obtained the reliable viscosity of molten silicon [1]. The logarithmic decrement of the oscillation was detected by using two photo sensors as the change of time intervals which a spot from the laser light passes through. The period of the oscillation was typically 3-5s with standard deviation of less than 0.3ms. Viscosity of the melt was calculated by using the successive approximation based on Roscoe's equation [2]. The temperature of the suspension wire was kept constant by circulating warm water around the wire housing because the elastic modulus of the suspension wire was changed by changing the temperature and affected the period of the oscillation. Atmosphere in the viscometer was dry helium that was inert chemically and had least viscosity. Furthermore, zirconium tips were placed just under the crucible to remove the oxygen in the atmosphere. Figures of the viscometer and details for the experimental procedures were described in the previous paper [1,3].

As an advantage of the oscillating method is that many materials are available as the melt container, highly sintered 99.5% alumina crucible was used, which was machined precisely, in this work. The inner diameter and the depth of the crucible were 16mm and 85mm, respectively. Inner diameter of the crucible at high temperatures was corrected with thermal expansion data [4]. The furnace consisted of three heating elements of $MoSi_2$, which were fine tuned independently for each measurement, and about thirty shielding plates of molybdenum placed above and under the crucible. As the results, very good temperature distribution around whole length of the crucible could be kept within 0.5K and the temperature at the top of crucible was carefully set slightly higher than that of the bottom to prevent the convection flow in the crucible.

Sample alloys were prepared by melting 99.9% iron and nickel in CaO crucible with induction heating under vacuum, and were cast to desired dimension. Although the density of the melt is very important parameter for calculating the viscosity, reliable density of Fe-Ni binary melt is not well known. Therefore, the density for each composition was determined by assuming the molar volume additivity between the components, iron and nickel whose densities were determined by authors.

3. RESULTS AND DISCUSSION

The measurements were carried out for five Fe-Ni alloys in the temperature ranges from the liquidus temperature to about 1880K. The experimental procedure is as follows; the measurement was started at the temperature about 50K higher than the corresponding liquidus temperature and the temperature was increased up to maximum temperature scheduled in advance, then was turned to decrease to confirm the reproducibility of the measurement until the melt solidified.

The results obtained including iron and nickel are shown in Fig.1. Lowest temperatures for the individual compositions were not necessarily consistent with liquidus temperatures due to the supercooling for some compositions. The viscosities show good Arrhenian behavior for all the compositions. Good Arrhenian straight line suggests that the melt consists of simple atomic sphere and almost no structure change such as the polymerization in spite of wide temperature range that reaches about 200K. Standard deviations for the scattering from the Arrhenian straight lines were about 0.2-0.4%. The maximum uncertainty accompanied by the measurement was estimated to be less than 3% by considering many factors such as the meniscus effect, dimension of the crucible, etc. in the same manner of author's previous work [(1)].

The isothermal viscosity curves obtained for 1773K, 1823K and 1873k are shown in

Fig.2. They decrease monotonously with increasing the content of nickel. This smooth behavior is considerably different from the literatures [4,5]. Bodakin *et al.* reported abnormally deep cave at an iron rich side in the isothermal kinematic viscosity, and Baum *et al.* contrarily reported big maximum near 30%Ni. Furthermore, their values of iron and nickel are about nearly 20% different from present value. The abnormal behavior found in the literatures is unlikely by referring the phase diagram of Fe-Ni as the reference of chemical thermodynamics. It shows almost solid solution type except iron rich side where BCC iron exists in small area and whole liquidus makes smooth concave curve. This type of phase diagram suggests almost no specified interaction between the components in molten state. Therefore, the smooth isothermal viscosity is considered to be reasonable.

Figure 3 shows the activation energy obtained against the composition. It also decreases monotonously with increasing the nickel content like to the isothermal viscosity. On the other hand, Bodakin *et al.* reported minimum at about 70%Ni [4]. As the activation energy for viscous flow, in general, increases with increasing melting temperature of the pure metallic elements, it is considered that present behavior is also reasonable and indicates the high reliability of the measurement.

As shown in the figures, the viscosity of molten Fe-Ni alloy shows relatively simple behavior. It is probably due to the similarity between the physical and chemical properties of iron and nickel.

4. CONCLUSION

Viscosities of molten Fe-Ni binary alloys have been measured precisely up to about 1880K in the entire composition range by using the improved oscillating viscometer. Viscosities obtained for all the compositions show good Arrhenian linearity in wide temperature range. The isothermal viscosities show monotonous curves that decrease from iron to nickel monotonously. The activation energy for viscous flow also decreases monotonously with increasing the content of nickel. These behaviors suggest that Fe-Ni alloy is a simple liquid and almost no interaction between the components of iron and nickel.

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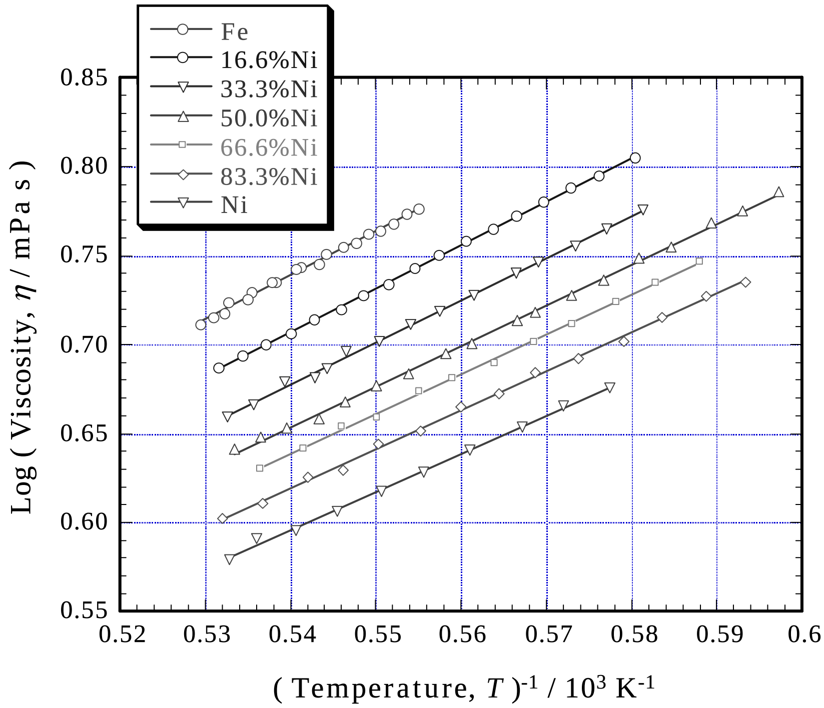

Fig.1 Viscosities of molten Fe-Ni binary alloys.

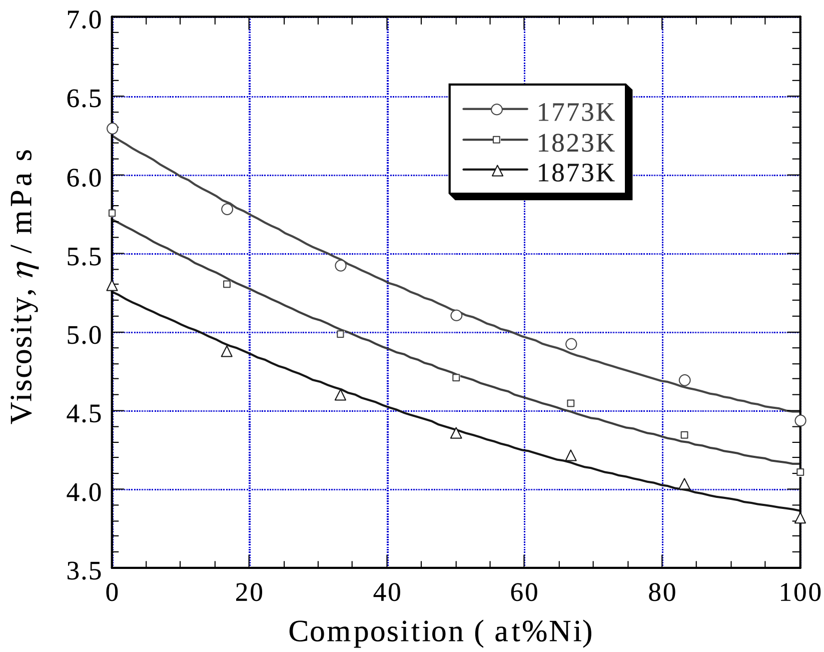

Fig.2 Isothermal viscosities of molten Fe-Ni alloy.

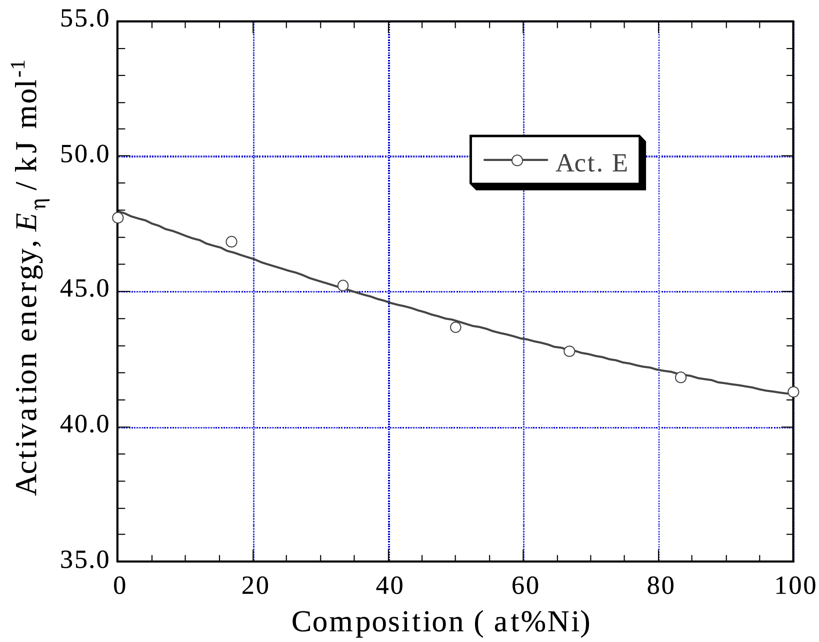

Fig.3 Activation energy for viscous flow of molten Fe-Ni alloy.